TITLE: Production At An Aircraft Plant

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STUDIES IN INTELLIGENCE

A collection of articles on the historical, operational, doctrinal, and theoretical aspects of intelligence.

A procedure for estimating the quantity of a particular kind of airframe produced at a particular Soviet plant.

PRODUCTION AT AN AIRCRAFT PLANT

Randolph Payne

The standard data required for estimating numbers of aircraft produced by a Soviet plant are the model of the plane and the approximate weight of its airframe, the floor area of the plant and the number of shifts it works, and the approximate date when production of this model began. A simple calculation from these data rests upon average figures that have been empirically derived for bombers, fighters, and transports respectively expressing pounds of production as a function of plant floor space: one need only multiply the floor area by this factor, adjust for number of shifts worked, divide by the weight of one airframe plus spare parts, and multiply by the number of months since production began to get the total number of units produced.

This method, however, is a comparatively crude one, in that it rolls into a single average some variables of considerable range—man-hours required per pound of production, worker density on the production line, and man-hours worked per month. In particular, it disregards the important increase in rate of production that is always achieved as a plant gains experience in building a new model. The graphic representation of this phenomenon is called the learning curve. It is the most important, versatile, and widely used of the many statistical tools employed by the U.S. aircraft industry in forecasting, planning, and evaluating the production of airframes.

The Learning Curve

The formula for the learning curve expresses mathematically a persistent and well-defined relationship between the hours of labor expended directly on airframe building and the number of airframes produced. With each doubling of the cumulative number of airframes built, the man-hours required per pound of airframe suffer a percentage decrease that is constant for any particular model. If the man-hour requirements decrease by 20 percent when twice as many airframes have been built, the rate of learning is reflected in what is called an 80-percent learning curve, because the direct labor required to produce the second frame is only 80 percent of that required for the first, that for the fourth only 80 percent of that for the second, that for the 400th only 80 percent of that for the 200th, and so forth. A relationship of this type, featuring successive powers of 2, has the convenient property of appearing as a straight line when graphed on logarithmic scales. Graphed arithmetically it appears as a curve of constantly changing slope as in Figure 1.

This form of the learning curve, which shows the man-hours required to produce any one of the series of airframes, is called a unit curve. There can also be constructed a cumu-

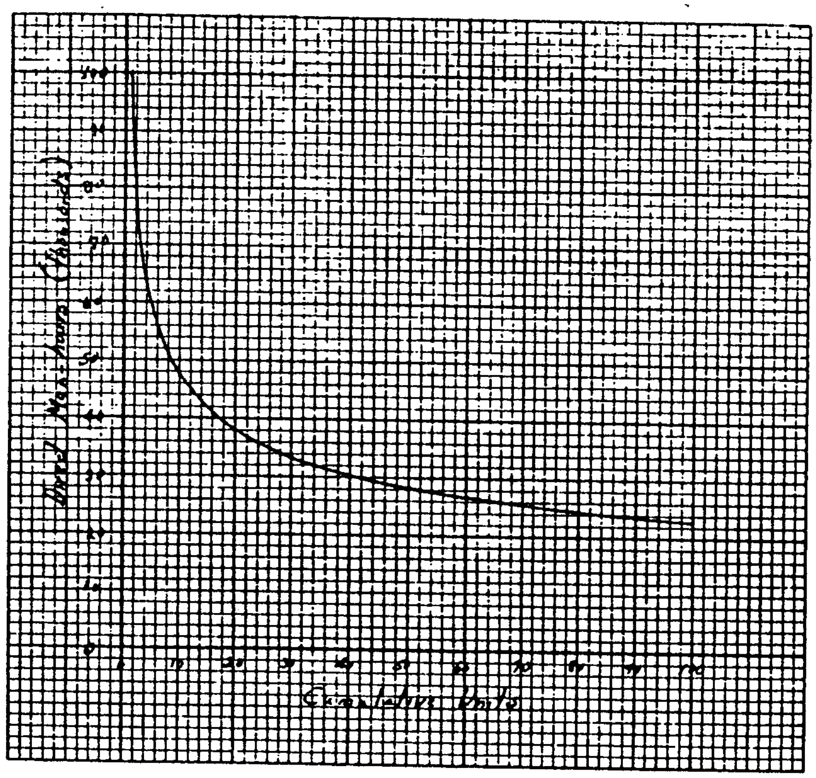

FIGURE 1. The 80-percent Learning Curve Plotted Arithmetically.

lative total curve to show the cumulative total of man-hours required for all airframes up through any given number in the series. Both are illustrated in logarithmic representation in Figure 2.[1]

The learning curve can be applied in estimating the production of a Soviet airframe plant with the assistance of four other standard curves also derived from the World War II and postwar experience of the U.S. airframe industry. These represent:

- Man-hours per pound of airframe required for production of the initial unit as a function of airframe weight (Figure 3).
- Floor area devoted directly to production as a function of total covered floor area (Figure 4).
- Square footage per direct worker on the largest shift as a function of airframe weight (Figure 5).
- Flow span (number of working days and cumulative man-hours expended from start of fabrication to initial flight) for the initial unit of production (Figure 6).

Crate and Coot

The refined methodology based on these curves is in general a matter of calculating the man-hours expended per month against the man-hours required for the initial unit of production and then, by application of the learning curve, for subsequent units. It can be illustrated by an account of how

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[1] The equation of the unit learning curve is

$$Y=aX^{n}$$

where

Y=direct man-hours required to produce airframe unit number X,
a=direct man-hours required to produce unit number 1,
X=any number of units produced, and
n=the slope (tangent) of the learning curve (log of the percent of the learning curve, expressed as a decimal, divided by log 2).

The cumulative total curve is closely aproximated by the definite integral from the first unit minus one-half to the last unit plus one-half. The integration gives the equation

$$y=\frac{a}{1+n}\left[(X+\tfrac{1}{2})^{1+n}+(\tfrac{1}{2})^{1+n}\right]$$

where y=total direct man-hours required to produce all units through unit X, the other symbols remaining as above.

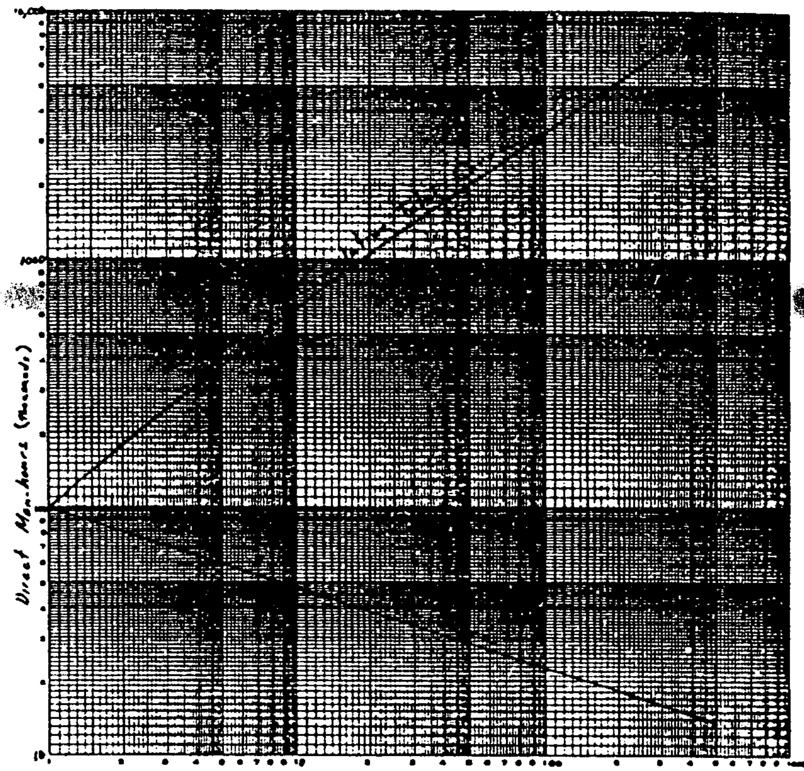

FIGURE 2. Cumulative and Unit 80-percent Learning Curves in Logarithmic Graph

it was used to estimate the production of the Soviet transport planes Il–14 (Crate) and Il–18 (Coot) at Moscow Airframe Plant No. 30. This estimate is a complex example in that it covered the phasing of the Crate aircraft out of production and the phasing of the new and much larger Coot in. In March 1959, when the estimate was made, the following information pertaining to the problem was available.

The total covered floor at Plant No. 30 was about 1.6 million square feet.

The plant was working two shifts per day.

The Crate airframe weighs about 16,000 pounds.

The first series-produced Crate was probably completed in December 1955.

In June 1956, according to the report of a visiting foreign delegation, the plant was tooling for series production of the Coot aircraft, and a prototype of the Coot was being tested.

In March 1957 Crate aircraft continued to be assembled while work on the Coot was in progress, it was reported by other foreign visitors.

In April 1957 the new Coot prototype was seen by foreign aircraft engineers.

The Coot was displayed publicly for the first time on 8 July 1957.

The Coot airframe weighs approximately 43,000 pounds.

The first series-produced Coot was probably completed in either August or September 1957; on 21 September, according to Tass, it successfully completed a test flight. A conservative estimate sets the start of series production at 1 September 1957.

That average parameters of production might be on the low side when applied to Plant No. 30 was indicated by the fact that it had received many awards for production and about 1,500 people had worked there for more than 20 years. On the other hand, negative allowances would have to be made for handicaps to production of the large Coot imposed by constrictions in Plant No. 30's final assembly building. About 955 feet long, 155 wide, and 40 high, this building was known to be interrupted by rows of columns, one of them running lengthwise through the middle of the building. The doors were only wide enough to accommodate the 104-foot wing span of the Crate; the Coot had a wing span of 124 feet. A foreign delegation visiting the plant in 1958 reported that several chords and other portions of the roof trusses had been cut out to allow the tail fins to protrude above the soffit of the lower members. Openings had also been cut into one outside wall, with lean-to's built around them, to accommodate one of the wings, the other being allowed to protrude through the row of columns that ran down the middle of the bay. The Coot fuselage was thus rendered immobile until the aircraft had been assembled completely, and then the outboard portions of the wings and the vertical tail assembly had to be removed in order to get it outside.

Crate Production

The application of the established parameter for man-hours required per pound of production according to total airframe weight (see Figure 3) gave an estimate that the first Crate airframe could have been produced for 20 man-hours per pound. But Plant No. 30 was here following in the footsteps of Tashkent Airframe Plant No. 84, the first to produce the Crate, and U.S. data indicate that the second builder of the same aircraft requires for his initial unit of production only

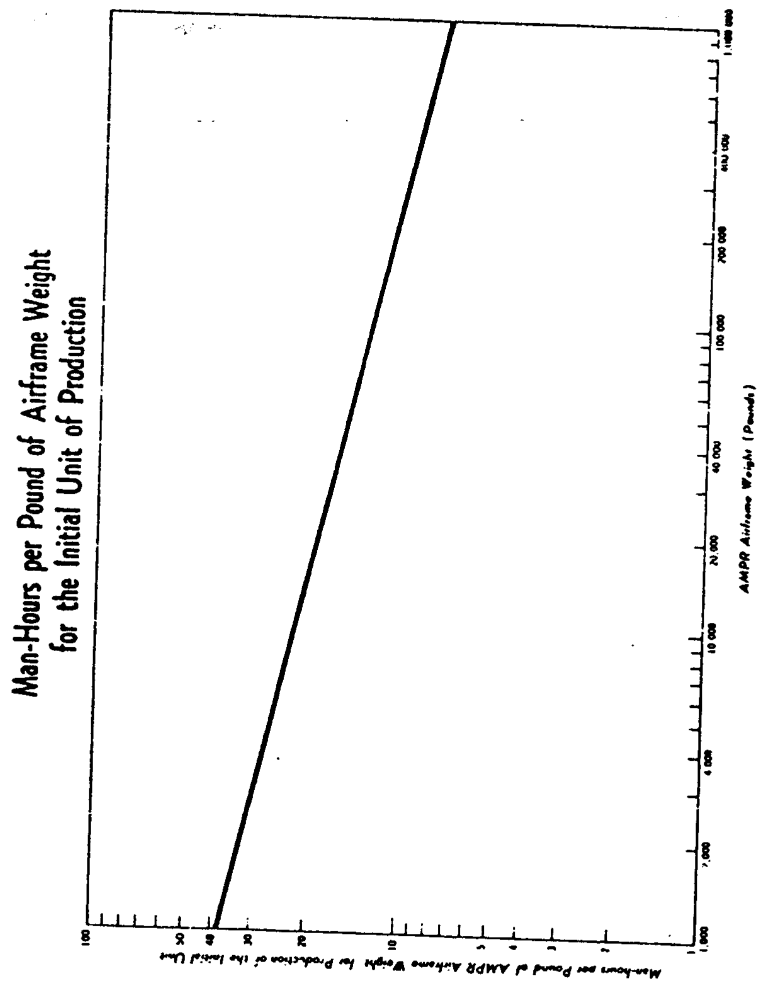

FIGURE 3

90 percent of the man-hours needed by the first. Thus Plant No. 30 was estimated to have produced its initial airframe at 18 man-hours per pound, a total of 288,000 man-hours for the 16,000-pound Crate. It remained to estimate the monthly rate at which these man-hours were expended.

The relationship between total covered floor area and that devoted directly to production (see Figure 4), applied to the 1.6 million square feet of Plant No. 30, gave a productive floor area of 650,000 square feet. The relationship between square

Relationship Between Total Covered Floor Area and Direct Covered Floor Area in an Airframe Plant

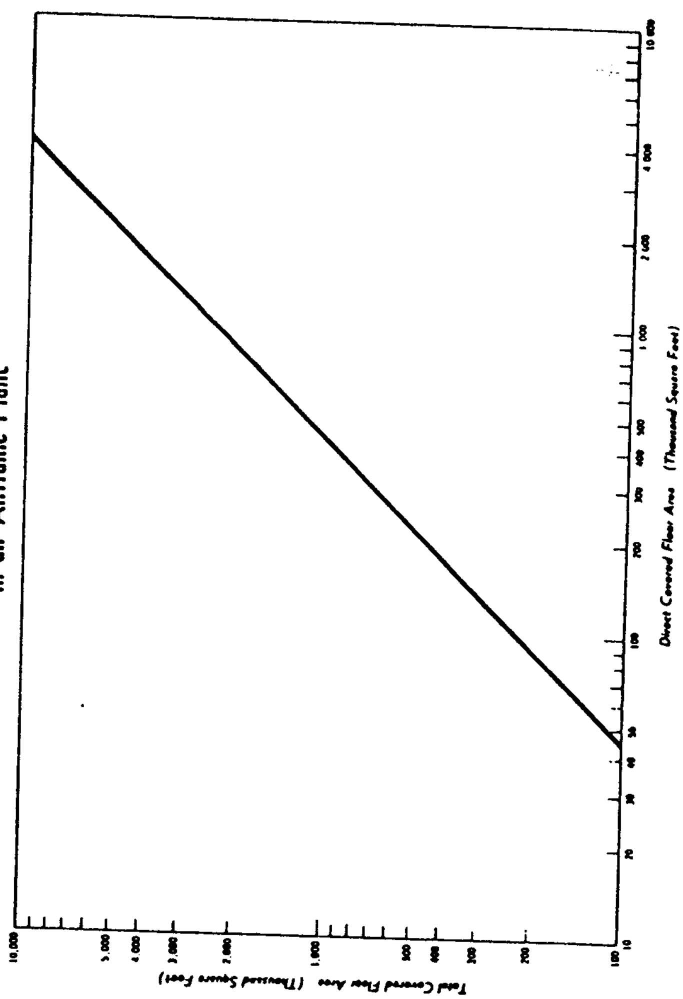

FIGURE 4

Relationship Between Square Footage per Direct Worker on the Largest Shift and Airframe Weight

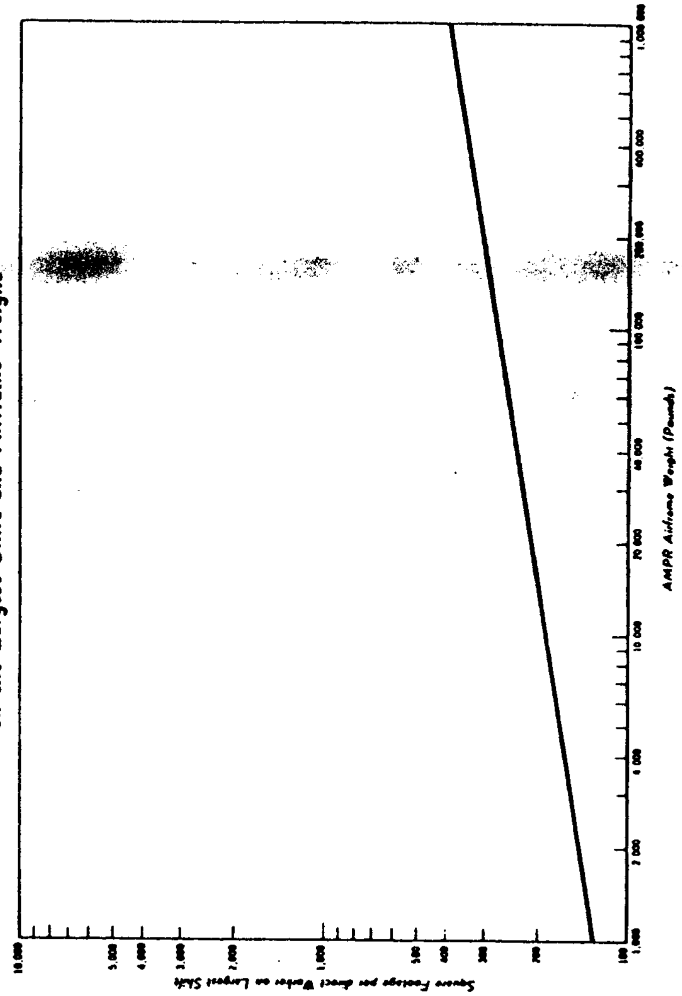

FIGURE 5

footage per direct worker and airframe weight (see Figure 5) showed for the Crate a requirement of 200 square feet per worker on the largest shift, which could thus use 3,250 workers in the 650,000 square feet. On the assumption that the second shift was 65 percent as large as the first, the total number of direct workers was estimated to be 5,360.

These workers were each assumed to work 8 hours five days per week and 6 hours on Saturday. Allowing 6 annual holidays, there would be 255 8-hour and 52 6-hour days, or a total of 2,352 hours, per year. A man's average working time in one month would then be 196 hours, which, however, was reduced by an 8-percent factor for direct workers doing indirect work, on sick leave, on vacation, and on rest periods, to yield 180 hours per month per worker. Multiplication by the 5,360 men gave 965,000 man-hours per month expended on the Crate. Allowing a 3.5-percent effort devoted to the production of spare parts, the man-hours per month remaining for unit airframe production figured about 932,000.

Dividing into this monthly expenditure the 288,000 man-hours calculated above to have been required for the initial unit gave a ratio of effort expended to effort required expressed in percentage as 323.6. That is, the initial unit was produced in December, 1955, at the rate of about 3¼ units per month, and the rate for succeeding units would increase according to the learning curve. The average learning curve for transport aircraft in the U.S. aircraft industry is 74.5 percent, but in estimating Plant No. 30's production of the Crate a 72.5 percent curve was used because of the many experienced workers at the plant and because of its past production record.

A schedule of Crate production could now have been compiled by accumulating the monthly expenditure of 323.6 percent of first-unit requirements and converting this into units of production in accordance with the 72.5 percent learning curve. But by 1956 production of the Coot had also been begun, and the full manpower in the plant was not being used on the Crate. An estimate had first to be made of the manpower requirements for production of the Coot in order to get a figure for the remaining manpower available for work on the Crate.

Coot Production

The initial unit of series production for the 43,000-pound Coot airframe would, according to the curve of Figure 3, have required 16 man-hours per pound, a total of about 688,000 man-hours. This figure was first used to determine when work on the Coot began through the correlation between man-hours required for initial unit production and working days from start of fabrication to initial flight shown in Figure 6.

Flow Span for Manufacture of an Aircraft from the Start of Fabrication to the Initial Flight, for the Initial Unit of Production

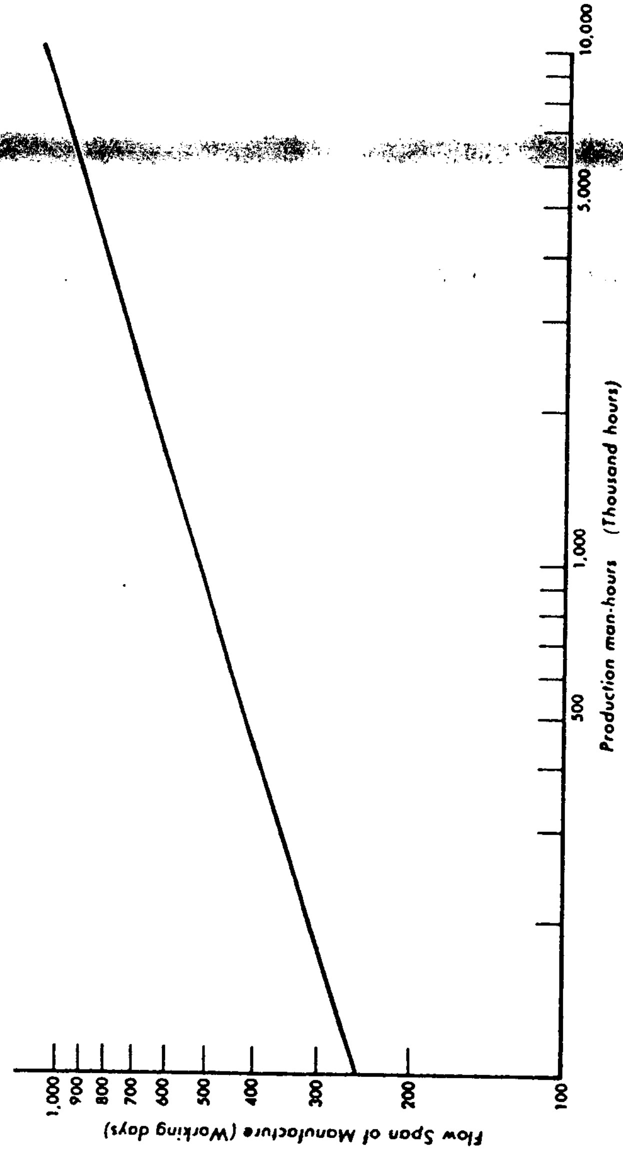

FIGURE 6

The 688,000 man-hours expended on the first series-produced Coot aircraft would, on the basis of experience in the U.S. aircraft industry, mean that 460 working days were required. Using a working day of 7.7 hours to allow for the short Saturday and the 196 hours per month calculated above for Crate production, the total elapsed time for the first Coot was found to be 18 months; but it was decided to increase this to 19 months because of the handicaps under which the Coot was being produced. This estimate, since it was established in our data that the first unit was completed in September 1957, put the start of fabrication sometime in February 1956.

Production of the Coot would have utilized about 240 square feet per worker on the largest shift, according to the worker density curve of Figure 5. With the productive floor area, 650,000 square feet, previously calculated for Plant No. 30 and again assuming the second shift to be at 65 percent the strength of the first, the total number of direct workers was estimated to be

$$\frac{650{,}000}{240} \times 1.65 = 4{,}570.$$

This figure was rounded off to 4,500 direct workers and multiplied as before by 180 hours per month to give 810,000 man-hours for the monthly expenditure of effort. The allowance of 3.5 percent for production of spare parts left about 782,000 productive man-hours per month expended on Coot airframe units.

The monthly expenditure of man-hours as a percentage of man-hours required for the initial unit then equaled

$$\frac{782{,}000 \times 100}{688{,}000} = 113.7,$$

giving a rate of production for the first unit of 1.137 units per month.

The average learning curve of 74.5 percent, which had been sharpened for the Crate, was slacked off to 76 percent in estimating Coot production to compensate for the handicaps under which the aircraft was being assembled. Using this curve to convert accumulated monthly expenditures of 113.7 percent of first-unit man-hours into units produced, the schedule of production shown in Table I was compiled.

Table I
Schedule of Production of Coot Aircraft at Moscow Airframe Plant No. 30
September 1957–March 1959

Year and Month	Cumulative Percentage	Cumulative Production	Monthly Production	Smoothed Monthly Production	Smoothed Cumulative Production
1957					
September	113.7	1	1	1	1
October	227.4	2	1	1	2
November	341.1	4	2	2	4
December	454.8	7	3	2	6
1958					
January	568.5	9	2	3	9
February	682.2	12	3	3	12
March	795.9	16	4	3	15
April	909.6	19	3	4	19
May	1,023.3	23	4	4	23
June	1,137.0	27	4	4	27
July	1,250.7	32	5	4	31
August	1,364.4	36	4	5	36
September	1,478.1	41	5	5	41
October	1,591.8	46	5	5	46
November	1,705.5	52	6	5	51
December	1,819.2	57	5	6	57
1959					
January	1,932.9	63	6	6	63
February	2,046.6	69	6	6	69
March	2,160.3	75	6	6	75

The Phasing Out

The device used to determine the number of man-hours that were devoted each month beginning with February 1956 to the Coot and therefore the number of workers out of the 5,360 total remaining available for Crate production was the Coot work-in-process curve shown in Figure 7. Here the expended cumulative percentages of first-unit man-hours represented by deliveries were plotted by month from September 1957, delivery date of the first completed unit. These form the straight curve "Completion of Production." Then each unit of production was plotted horizontally to the left at a distance representing the lapsed time from start of fabrication to completion, 19 months for the first unit and reduced by a learning curve for succeeding units. These form the "Loading Line." Perpendiculars were drawn to this curve from the

USSR: Work-in-Process Curve for Coot (Il-18) Transport Aircraft

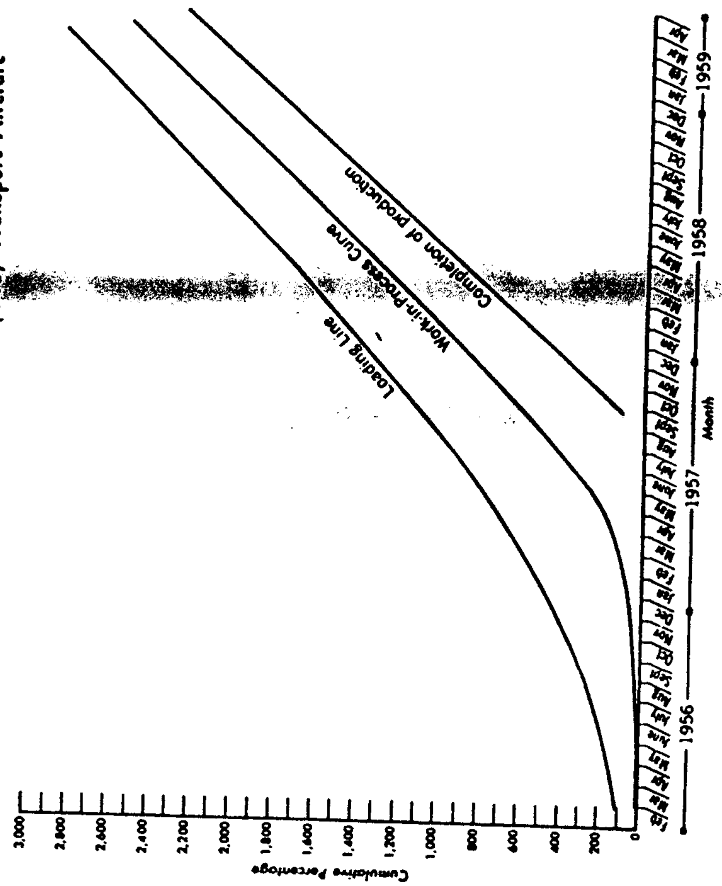

FIGURE 7

Completion of Production line, and a third curve was drawn through the mid-points of the perpendiculars and arbitrarily faired from the origin to the first perpendicular. This is the work-in-process curve.

This curve determined by month the cumulative percentage of first-unit man-hours devoted to Coot production, and the difference between successive percentages was the percentage expended each month. The latter were multiplied by the number of man-months required for the initial unit (688,000 over 180) to give the number of workers absorbed each month by the Coot. These were then subtracted each month beginning with February 1956 from 5,360 to yield the manpower base left for Crate production. The results of the calculation are listed in Table II.

Table II

Production of Crate Aircraft at Moscow Airframe Plant No. 30 as Affected by Phasing In of Coot
December 1955–June 1958

Year and Month	Cumulative In-Process Percentage for Coot	Smoothed Monthly Percentage for Coot	Direct Workers for Coot Production: Complete Units	Direct Workers for Coot Production: Complete Units and Spare Parts	Direct Workers Remaining for Crate Production: Complete Units and Spare Parts	Direct Workers Remaining for Crate Production: Complete Units Only	Percentage of First Unit Man-Hours Expended Monthly	Cumulative Production of Crate Units
1955								
December	...	...	...	...	5,360	5,179	323.6	4
1956								
January	...	...	...	...	5,360	5,179	323.6	14
February	...	...	...	...	5,360	5,179	323.6	27
March	1	1	38	39	5,321	5,141	321.2	43
April	3	2	76	79	5,281	5,102	318.8	64
May	7	3	115	119	5,241	5,064	316.4	87
June	12	5	191	198	5,162	4,987	311.6	114
July	19	6	229	237	5,123	4,950	309.3	143
August	25	8	306	317	5,043	4,872	304.4	175
September	32	9	344	356	5,004	4,835	302.1	210
October	44	12	459	475	4,885	4,720	295.0	246
November	59	14	535	554	4,806	4,643	290.1	286
December	73	16	612	633	4,727	4,567	285.4	326

1957								
January	92	20	764	791	4,569	4,414	275.8	368
February	118	24	917	949	4,411	4,262	266.3	410
March	148	30	1,147	1,187	4,173	4,032	251.9	452
April	188	39	1,491	1,543	3,817	3,688	230.4	493
May	240	53	2,026	2,097	3,263	3,153	197.0	528
June	322	79	3,019	3,125	2,235	2,159	134.9	552
July	418	91	3,478	3,600	1,760	1,700	106.2	572
August	510	96	3,669	3,797	1,563	1,510	94.3	590
September	612	100	3,822	3,956	1,404	1,357	84.8	607
October	713	101	3,860	3,995	1,365	1,319	82.4	624
November	815	102	3,898	4,034	1,326	1,281	80.9	639
December	918	103	3,937	4,075	1,285	1,242	77.6	654
1958								
January	1,022	104	3,975	4,114	1,246	1,204	75.2	669
February	1,121	104	3,975	4,114	1,246	1,204	75.2	686
March	1,223	105	4,013	4,153	1,207	1,166	72.8	701
April	1,330	105	4,013	4,153	1,207	1,166	72.8	717
May	1,436	105	4,013	4,153	1,207	1,166	72.8	732
June	1,543	106	4,051	4,193	1,167	1,128	70.5	746

Validation

Information received since these estimates were made indicates that at least 736 Crate aircraft were produced at Plant No. 30. This figure compares well with the total of 746 in Table II. The estimate of Coot production, however, was less accurate; it was learned later that the second work shift at the plant was probably discontinued in 1958. Production therefore reached a rate of 4 Coots per month, not in April 1958 as estimated, but only in October. As of 1 October 1958 the total produced is believed to have been 33 instead of the 41 given in Table I, and production remained constant at the rate of 4 per month through 1960.

These results show that successful application of a methodology is dependent on how well the seasoned judgment of the analyst can cope with the imponderables and on the accuracy of the intelligence information used in the calculations. Calculations under any methodology, although useful in the absence of more direct information, never preclude the need for concrete and reliable intelligence on the production of Soviet aircraft.